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Analysing manufacturing enterprises to identify opportunities for automation and guide implementation – a review.

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Abstract: This paper is a review of the current literature on modelling industrial processes and integrating automation along with the digitisation drive of Industry 4.0 with the purpose of identifying promising directions for future research. Future research will involve working with an automation integration company to develop and test a methodology for assessing manufacturing enterprises to identify areas or processes that can economically be made more efficient through robotics and automation. The expected outcome of the research will be a system that streamlines and speeds up automating and digitalising the manufacturing industry. Copyright © 2019 IFAC

Keywords: Automation, Data processing, Efficiency enhancement, Industrial production systems, Manufacturing processes, Modelling, Robotics, System analysis.

1. INTRODUCTION

Currently there is a lot of enthusiasm and investment in automation and robotics from the UK government to compete in a rapidly changing world (Department for Business Energy & Industrial Strategy, 2018). The rate of change in technology is also increasing and to stay relevant and competitive companies will have to adapt (Benešová & Tupa, 2017). However, there can be a lack of knowledge and experience of implementing automation in industry and this can lead to a bottleneck for realising Industry 4.0 (Ahuet-Garza & Kurfess, 2018). Fully automating manufacturing is not the goal but rather combining manual and automated operations to benefit from the efficiency and productivity of automated systems and the flexibility of people (Winroth et al, 2006). A methodology would be helpful that can be applied by trained individuals to analyse the processes of small and medium sized enterprises (SME's) to identify economical and feasible opportunities for automation to increase production efficiency (Chen & Small, 1996). Many available solutions involve automating individual workstations or tasks and are successful in this. However, if the processes are not modelled at the enterprise and process levels these individual projects have been shown to have limited financial benefit (Aitken, 2018).

This paper is structured as follows: Section 2 briefly discusses related works; Section 3 describes the problem; Section 4 outlines the proposed approach; Section 5 further expands the literature review that has been completed and is split into three sub-sections: Industry 4.0, modelling of manufacturing processes, and implementation. Then other

considerations are related in Section 6, next steps to be taken are described in Section 7, and preliminary conclusions are discussed in Section 8 followed by the references.

2. RELATED WORKS

A review of current research in the field of modelling manufacturing processes and automation has been conducted. Some areas of similar research have been identified but they do not address the specific problem of modelling existing manufacturing enterprise processes to identify opportunities for automation. Mohammad et al, (2017) propose a specification for a smart factory but this is for a new factory rather than modifying an existing facility.

The consequences of Industry 4.0 and digitalising work on employees are analysed by Wilkesmann & Wilkesmann (2018) and this consideration of the qualitative effect on workers will be used as one factor in the return on investment. The use of hybrid petri nets to redesign processes by Cavone et al (2018) is a good example of modelling but deals only with low automated processes. A methodology for modelling and assessing human activities within cyber-physical systems is proposed by Fantini et al (2018) and the authors suggest future work towards formal and quantitative methods to model human activities. While their findings will be considered the worker is only part of the whole production process that will be modelled. Verhagen et al, (2015) propose a method for automatically deciding on automation for non-manual tasks based on information waste but it is not applicable to manual tasks or physical production processes.

3. PROBLEM DESCRIPTION

The research aim is to develop a system for a company that builds and integrates automation to use in assessing the automation needs of their SME customers.

The developed methodology for modelling and implementation would need to satisfy several considerations. For example, it must be able to make a quick assessment of the manufacturing process with respect to parameters such as: volume, variety, extent of human intervention required, hazards for human operators, interface requirements concerning production management systems such as ERP, quality management systems, inspection systems, automated storage and retrieval (AS/RS) systems. For this to happen efficiently it is necessary to know which questions to ask and which data is most important to gather.

The final method must provide the basis for technology choices based on parameters of the available technology types such as speed of processing, reconfigurability to accommodate product variants, programmability, change tools and grippers, interface with existing communications systems and networks and compatibility of programming languages. The method should be usable by small technology companies as well as any company wishing to use technology and therefore it will need to include information about the relative performance of different equipment options. To reliably recommend the most appropriate technology a database of available options along with their specifications will be developed and maintained.

Furthermore, the research must also provide a basis for transitioning from the current state by supporting implementation planning and phased change-over including the assessment of training requirements. It should provide a method to develop a cost for the proposed new technology considering quality improvement and increased output. This requires a holistic approach to calculating return on investment (ROI) that is not simply based on the salary of workers who could be repurposed.

Research questions to be answered are:

How can manufacturing and financial data be used in a method to specify an automation solution that increases overall efficiency?

Which data needs to be gathered to specify automation solutions (minimize as much as possible)?

How can the approach financially justify the investment?

4. METHODS

4.1 Literature Review

An initial broad literature review was undertaken using classic search by keywords such as 'Industry 4.0' in journal databases to develop an understanding of the direction the manufacturing industry is moving in. From these initial widely cited papers interesting citations were investigated (snowball action). The problem of modelling manufacturing

was then investigated using search terms such as 'modelling manufacturing' and papers were selected based on title first, then reading of abstract to decide relevance and finally reading of the conclusions and relevant sections of the body. Publications searched included the major peer-reviewed journals: International Journal of Production Research, Production Planning and Control, International Journal of Production Economics, International Journal of Operations and Production Management and International Journal of Advanced Manufacturing Technology.

5. LITERATURE REVIEW

5.1 Industry 4.0

The idea of Industry 4.0 was first proposed in Germany as part of a government initiative to maintain the country's position as "one of the most competitive manufacturing industries in the world" (Kagermann, et al., 2013). Another term that is used to describe future production is smart manufacturing which is about autonomy, evolution, simulation and optimisation of the manufacturing enterprise (Kusiak, 2018).

Lee et al., (2013a) discuss trends in predictive manufacturing systems which deal with the invisibles and uncertainty in manufacturing by making the machines more self-aware. They stress that data is only useful when processed to provide context and meaning for example OEE is a useful metric of machine performance but does not show which contributing factors may be causing reductions. Connecting sensors to machines and machines to other machines is a necessary first step to gather data but then software is needed to process the data which performs four tasks: processing signals and extracting features, health assessment, predicting performance, and diagnosing faults. This allows cost effective just in time maintenance of equipment. In another paper in the same year Lee et al., (2013b) proposes that predictive manufacturing based on big data can be used to solve problems in both visible and invisible spaces.

A review and analysis of academic progress by systematic literature review was conducted by Liao et al. (2017). They summarise the main research directions and indicate areas that are under developed and present opportunities for future research. They identified Kagermann, et al., (2013) as the most cited reference in their review and consequently that the definition of Industry 4.0 contained within could reliably be used. They also found that 95.1% of Industry 4.0 research was conducted in the laboratory and only 4.9% in industrial applications which shows a lag in commercial uptake.

5.2 Modelling of Manufacturing Processes

Yadav and Jayswal (2018) review the modelling of flexible manufacturing systems (FMS) by conducting a literature review of past papers in the field. They cover mathematical models which have been in development since 1980, artificial intelligence models, hierarchical models, multi criteria decision making (MCDM) models, petri net models and simulation models and present some conclusions about the benefits and limits of each. They also suggest future work

could be done to compare different modelling techniques and that FMS can be combined with Industry 4.0 using AI.

A factory redesign and improvement (FDI) activity model using ICAM definition for functional modelling (IDEF0) is introduced by Jung et al. (2017). The FDI model shows the dependency between activities and control levels and the information and software relied on by each activity to design new and improve existing factories. They tested their FDI activity model with a use case in an industrial setting and identify future work to develop an information model to integrate activities and map them to identify gaps in existing standards and fill these gaps with new standards. They also suggest the activity model could be used to construct performance metrics. Wang et al, (2010) also models industrial value chains using IDEF0 to rigorously define activities in the system and the relationships between them. Modelling methodology such as IDEF0 and value stream mapping (VSM) are discussed by Seth et al, (2017). They find that these 'paper based' modelling techniques provide a good overview of processes but do not consider quantities or time.

Value stream mapping has been used successfully for a long time. In 1999, Rother and Shook set out five steps to implement lean manufacturing in an organisation. These are 1. find a change agent, 2. find a sensei, 3. seize a crisis to motivate action 4. map the entire value stream, 5. pick something important and start removing waste. They highlight the problem that most readers skip step 4 (VSM) and jump to picking something important and getting started removing waste. This results in fixing one small part of the process, but this is undermined by bottlenecks in other areas resulting in no cost savings. An alternative to Value Stream Mapping (VSM) that addresses its limitations in showing most types of waste is the waste identification diagram (WID), (Dinis-Carvalho et al., 2015). This uses the dimensions of its symbols to convey information about production units and in their paper was found to be more effective than VSM when representing complex production units but suffered from a lack of information flow representation.

Delgado-Maciél et al. (2018) present a comparison between modelling inventive problems with Functional Analysis (FA) and the Causal-Loop diagram (CLD). They found that the FA diagram can facilitate potential tool selection and the CLD explores the impact of system modifications and that the approaches are complementary and suggest future work to propose a methodology that combines FA and CLD and test it in different scenarios. They also examine the use of the Theory of Inventive Problem Solving (TRIZ) and find advantages in its knowledge-based approach but that the learning process is time consuming so its combination with other tools is desirable.

Testing of theories is done using laboratory test equipment and in real life manufacturing plants. A plant model constructed from interconnected discrete Petri Net models is proposed by Hernández-Martínez et al., (2016). They claim the model is generic and scalable and contains information about restrictions, concurrent production routes, equipment

availability, storage limitations etc. and present a procedure to codify the model into a software program. The system is trialled using a prototype manufacturing cell, a PLC and a software application running in Matlab. Park and Li (2018) use a case study of improving the productivity of a motorcycle manufacturing plant to test their technique of structural modelling to simplify the process through aggregations and transform it into a Bernoulli line model. They then use Markov chain analysis to estimate system throughput and validate their results with plant data. They claim that their method provides quantitative analysis and that it is applicable to other manufacturing industries.

Material flow simulation is performed by several industrial software packages, but these require a lot of work to set up, parameterise and adapt (Fischer et al, 2017). They suggest a generic simulation environment to integrate and define simulation workflows and that standardisation of tools such as a standard API and data model would aid implementation. Automation Markup Language (AutomationML or AML) is used as the base format in their paper. They also set out the requirements of a simulation environment; support for discrete event and agent-based methods, automatic model generation, probabilistic simulation and the ability to output meaningful KPIs

A survey was conducted by Oppelt et al. (2015), of 221 individuals on the use of simulation within industry. Findings of the survey included that most decisions are based on individual experience or on standards, but that simulation can answer earlier and with less risk engineering and operational questions. Another finding was that the future of simulation would be to cover the whole life cycle of the plant, merging design, engineering, training and operations but that the handover from engineering to operations is the biggest barrier to continuous use of the simulation. In the future plants will be built virtually first and existing plants will not make changes without first simulating them. Equipment suppliers will need to supply virtual models of their products that can be plugged in to the simulation. While the plant operates its virtual twin is also running allowing scenarios to be tested to optimise the real plant.

Aitken, (2018) the COO of Lanner describes digital twins in detail and suggests that more than one digital twin is required and that they should be split into three levels: asset level, operational process level and enterprise business level. Digital twins are described as "Dynamic digital representations that enable companies to optimise the performance of their assets, processes and business". They state that at operational and enterprise levels the digital twin is process based rather than asset based and must have a form of logic emulation and simulation to provide value analytically. This echoes the aims of the current investigation in that modelling of the whole enterprise is necessary to identify the processes and areas where resources spent on automation will return maximum ROI.

A hybrid simulation (HS) modelling system that integrates discrete event simulation (DES) with agent-based modelling to help companies cope with the increased complexity of moving to product service systems (PSS) was proposed by

Rondini et al. (2017). They found that their hybrid system outperformed DES alone in a test case. One application of modelling is to create virtual reality environments. Turner et al., (2016) propose discrete event simulation (DES) and virtual reality use in industry. The value of the visualisation provided by 3D representations of DES is that they can be used to test “what if” scenarios in a few hours as opposed to manual methods which take much longer. They note that the currently available visualisation engines lack the level of detail and features provided in the computer game industry.

5.3 Implementation

Kaartinen et al, (2017) propose a digital manufacturing toolbox to support implementation of Industry 4.0 technologies in SME's to increase competitiveness and save money. It covers five areas; manufacturing design and production simulation, production automation, robotics, additive manufacturing, digital scanning and measuring.

To analyse big data Lee et al. (2014) stipulate that the deployment platform choice must consider speed of computation, cost, deployment difficulty and future updateability. They also discuss the trend towards servitization which is defined as adapting an organisation's capability to “selling an integrated product and service offering that delivers value in use”. Another interesting point they make is that product quality can be used to feedback into system management and improve production scheduling. Lee et al. (2014) also champion the idea of industrial machines becoming self-aware and self-maintained (assessing its own health and using similar information from peers to make predictive maintenance decisions). The system they propose to do this is prognostics and health management (PHM) based on self-learning clustering of the knowledge base.

6. OTHER CONSIDERATIONS

6.1 Sustainable or Green Manufacturing

There are also opportunities for sustainable manufacturing in Industry 4.0 (Stock and Seliger, 2016), and these will be considered as advantageous for the methodology to consider. The energy savings and reduction of other wastes are key principles of Lean Manufacturing and the model can be used to test different scenarios of waste reduction.

6.2 Standardised Terminology

Garretson et al, (2016) propose standardised terminology to support manufacturing process characterisation and the researcher will attempt to follow this as it is believed standardisation aids clarity in research. When using IDEF0 modelling techniques every effort will be made to follow the syntax and semantics set out by the IEEE standards. (Engineering Standards Committee of the IEEE Computer Society, 1998).

7. NEXT STEPS

Further research to identify related work, possible approaches, modelling tools and enable a critical review of existing theory is still necessary. This will include; modelling

methodology, integration of technology, robotics and automation in manufacturing, design and implementation of automated processes and production facilities, manufacturing management software and ERP, and the latest research on Industry 4.0. This research will be used in the specification of requirements that the method must fulfil and in synthesis of a new method.

The research will also involve a large component of field work at the customers site from the initial overview visit through to more detailed investigation of each process. This will form the basis of case studies of technology implementation. The investigation will mostly be in the form of interviews with management and staff and these as well as providing data for the model will also be used to refine the data gathering methodology further. Shadowing staff to gain an understanding of the processes they perform will be another method of recording information for the model. The implementation of the selected solution will also be overseen by the researcher and this will yield insights into the economic and practical realities of implementing automation in a manufacturing environment. Management will then be interviewed again using a Likert scale or similar method to gauge qualitatively the usefulness of the methodology in assessing their systems and selecting the best automation alternatives to introduce. New knowledge will be discussed with reference to current literature and conclusions will be recorded.

8. CONCLUSIONS

8.1 Theoretical Implications

New knowledge will be created by combining existing modelling theories in a new way and applying them to a new environment. This will allow testing the applicability of modelling theories in different situations from that which they were originally designed for. The theories' effectiveness in combination with each other will also be interesting to investigate and may provide useful data.

8.2 Practical Implications

The culmination of the research is expected to be the development of a marketable system for modelling manufacturing processes and integrating automation. This will be evidenced by the successful modelling and integration of automation at an SME's manufacturing plant. The methodology will allow technology companies to model the processes used in any manufacturing company and quickly ascertain the areas where automation will be beneficial and specify the parameters of the expected solutions. The model will provide the basis for design and implementation of automation solutions to deliver the maximum efficiency savings with the available resources. It will work for SME's that are limited for time, expertise and capital expenditure but which can benefit from Industry 4.0. The opportunity of access to a manufacturing company to test theoretical methods in the real world contributes to the originality of the research. The case study location will gain a greater understanding of their facility as well as an installed automation solution which will create a measurable

efficiency saving. Other SME's will also be able to receive analysis and profit from the methodology in the future. The UK economy gains an advantage in the competitive manufacturing sector from a greater uptake of automation.

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